LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-426347

STANDING WAVE PROBES FOR DIMENSIONAL METROLOGY OF LOW DENSITY FOAMS

R. M. Seugling, S. C. Woody, M. B. Bauza

March 25, 2010

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

STANDING WAVE PROBES FOR DIMENSIONAL METROLOGY OF LOW DENSITY FOAMS

R M Seugling, S C Woody and M Bauza

Introduction

Typically, parts and geometries of interest to LLNL are made from a combination of complex geometries and a wide array of different materials ranging from metals and ceramics to low density foams and plastic foils. These parts are combined to develop physics experiments for studying material properties, equation of state (EOS) and radiation transport. Understanding the dimensional uncertainty of the parts contained within an experiment is critical to the physical understanding of the phenomena being observed and represents the motivation for developing probe metrology capability that can address LLNL's unique problems.

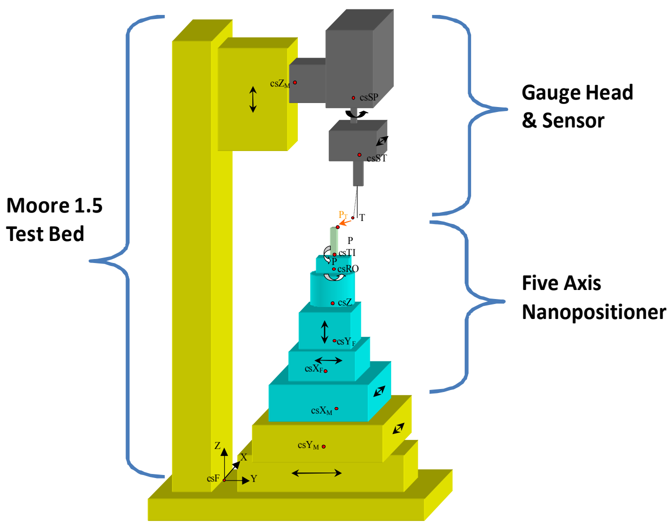

Figure 1: Illustration of measurement system used for the characterization of the standing wave probe performance.

Standing wave probes were developed for measuring high aspect ratio, micrometer scaled features with nanometer resolution. Originally conceived of for the use in the automotive industry for characterizing fuel injector bores and similar geometries [1-2], this concept was investigated and improved for use on geometries and materials important to LLNL needs within target fabrication. As part of the original project, detailed understanding of the probe dynamics and interactions with the surface of the sample was investigated [3]. In addition, the upgraded system was utilized for measuring fuel injector bores and micro-lenses as a means of demonstrating capability [4].

This report discusses the use of the standing wave probe for measuring features in low density foams, 55 mg/cc SiO_2 and 982 mg/cc (%6 relative density) copper foam respectively. These two foam materials represent a difficult metrology challenge because of their material properties and surface topography. Traditional non-contact metrology systems such as normal incident interferometry and/or confocal microscopy have difficulty obtaining a signal from the relatively absorptive characteristics of these materials. In addition to the foam samples, a solid copper and plastic (Rexolite™) sample of similar geometry was measured with the standing wave probe as a reference for both conductive and dielectric materials.

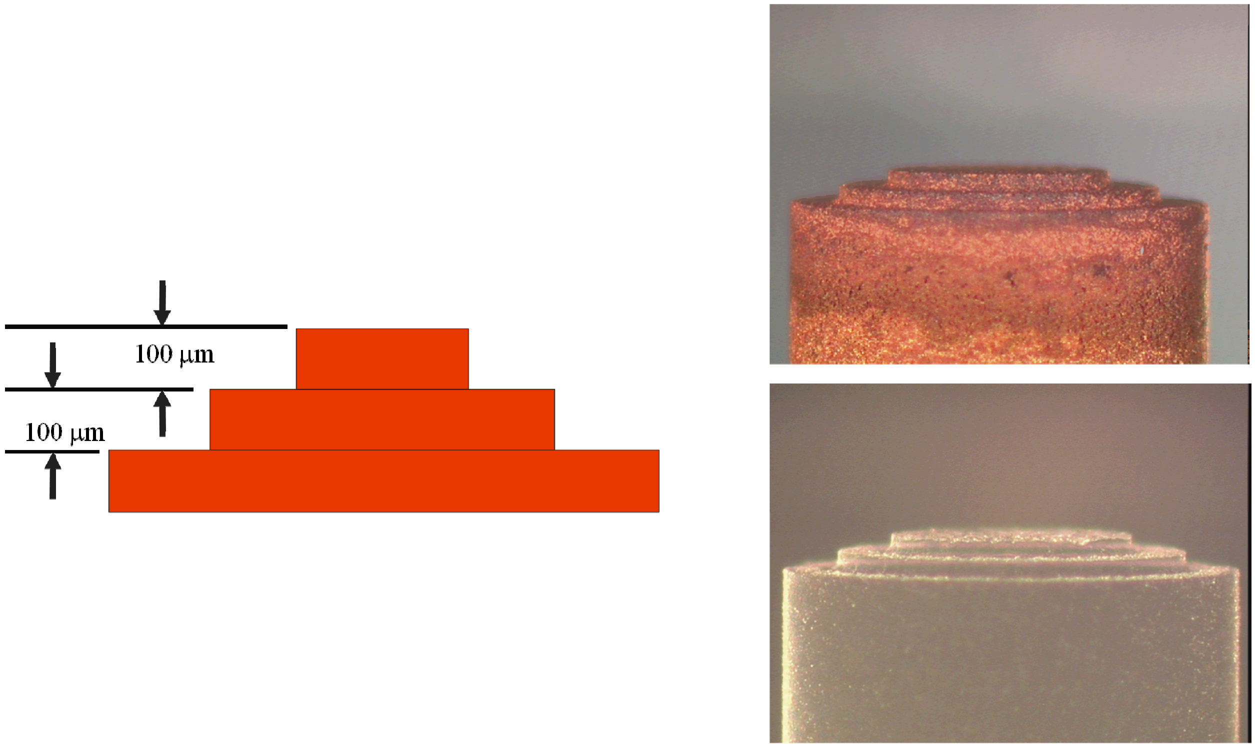

Figure 2: Left; Schematic of the stepps machined into solid and foam samples for testing the standing wave probe. Top-Right: 6% relative density copper foam. Bottom-Right: 55 mg/cc SiO_2 aerogel sample.

Experimental Set-up

To qualify the standing wave probe system on material of interest to LLNL, a metrology platform was developed at Insitu Tec Inc and is illustrated in Figure 1. The denoted five axis nanopositioning stage is an Aerotech Fibermax™ with < 10 nm positioning control mounted onto a Moore 1.5 measuring machine platform. The platform is chosen for its high mechanical stiffness and structural stability. The Z-axis column of the Moore has a custom gauge head equipped with a nanometer spindle having <10 nm asynchronous error motion and a linear piezo driven stage providing <0.1 nm positioning noise. The linear stage is designed to move along the radial direction of the rotating axis and operates under closed-loop control from the SWP output allowing for scanning of the sample surface. The standing wave probes are kinematically mounted onto the nanopositioner carriage. Also, the sensitive axis of the probe is designed to align along the same axis as the nanopositioner's motion to minimize offset errors. For these experiments the rotation axis was locked into a fixed position and the measurement was done using the combined piezo scanning stage and the Y-axis of the Aerotech Fibermax™. Because of the fairly large structural loop and stacked configuration of the experimental set-up the combined measurement uncertainty was calculated to be 100 nm over the area of interest for this application.

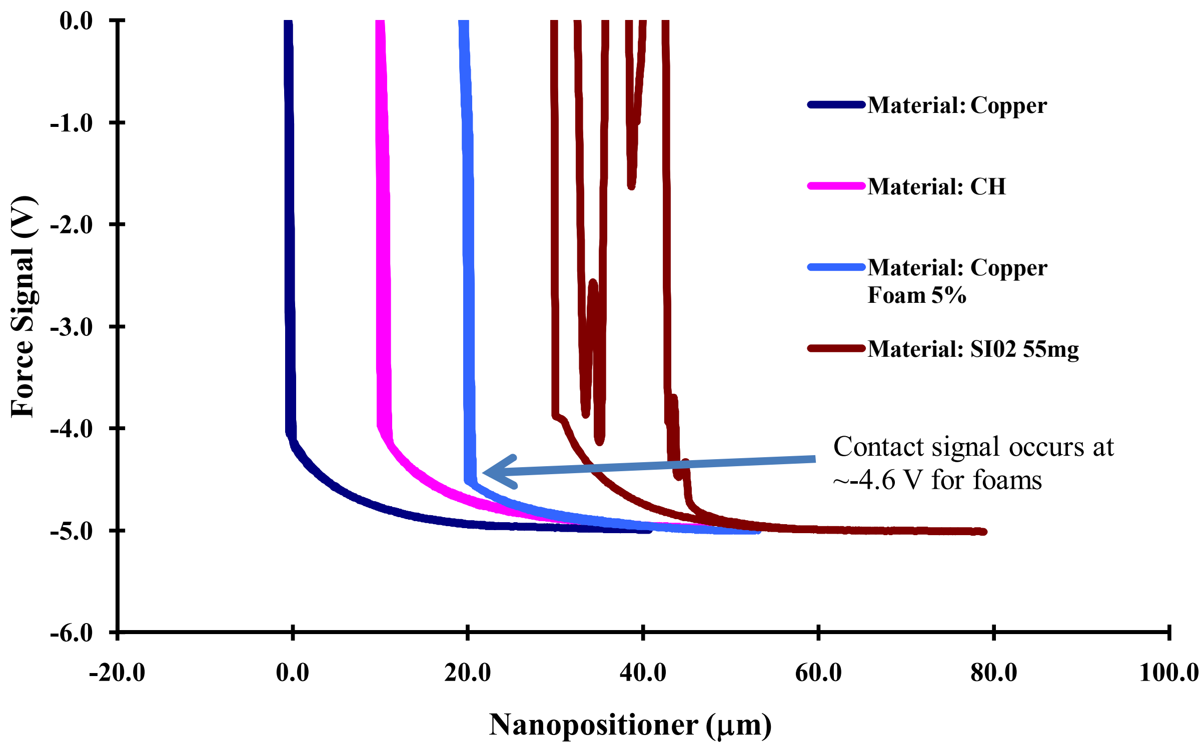

Figure 3: Sensitivity plot for the four different materials under investigation.

Four artifacts were manufactured from three different materials to investigate the probes performance. Step features of approximately 100 µm were machined into the face of cylindrical blanks as shown in Figure 2. Two of the samples were machined from solid copper and CH (Rexolite) to determine the effects of static charge on the probes ability to accurately locate a surface. The second two samples were made from low density foams, 6.0% relative density Cu and 55 mg/cc SiO_2 respectively.

The probe was calibrated for the material of the sample being measured by running a sensitivity scan where the probe is moved into contact with the surface while the output of the probe is being monitored. In air, the probe output is constant and increases nonlinearly as the probe tip approaches the surface. As the probe contacts the surface of the sample an abrupt change in signal is apparent. Figure 3 shows the results of the calibration curves for the four samples measured during this study. To mitigate damage to the surface of the sample, primarily for the low density foams, the probe was operated in a non-contact mode. In this case the probe output signal was closed-loop controlled to a value just below the contact point. The difference between the contact signal and the trigger signal used in non-contact mode is referred to as the offset. This offset represents approximately 1.0 µm of displacement between the probe tip and the surface of the sample being investigated. Although this represents a absolute error in position of the surface, during relative measurements, as described in this study, this offset represents a repeatable value that is not important to relative measurements.

Results

Each of the four samples were measured using the same standing wave probe in the set-up described previously. The surface was scanned nominally across the center section of the stepped feature. Figure 4 and Figure 5 show results of both contact and noncontact scans of the solid copper sample. The variation in step height between the two methods is on the order of 0.3 µm.

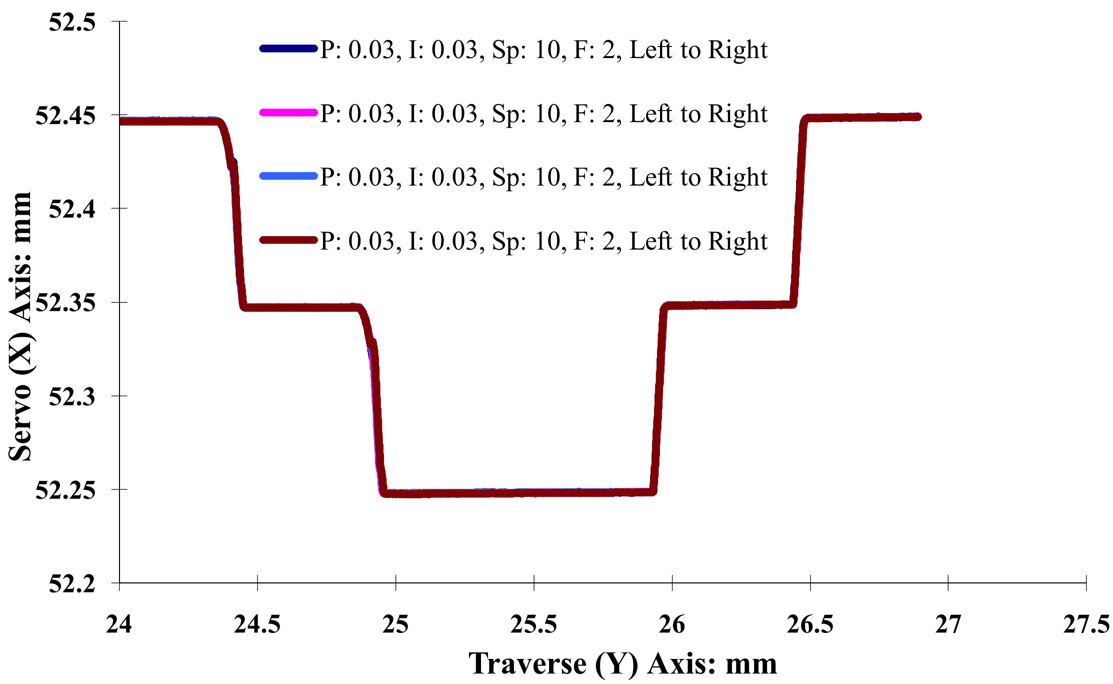

Figure 4: Solid copper stepped sample scanned data in contact mode

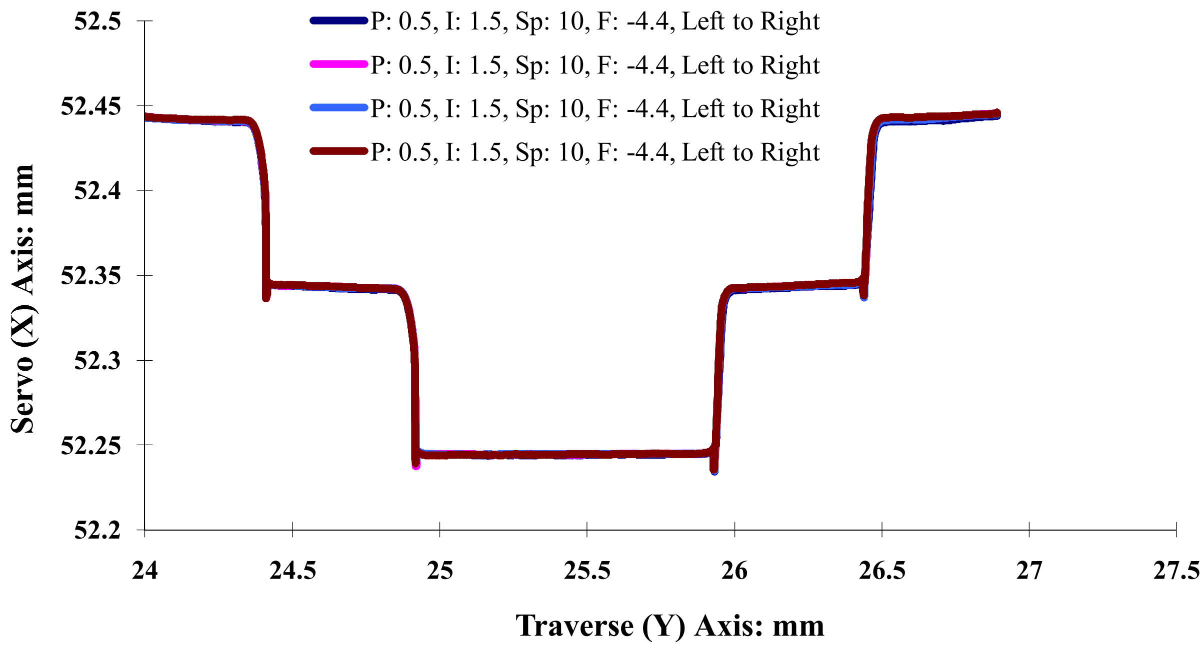

Figure 5: Solid copper stepped sample scanned using non-contact mode.

In a second test a solid CH sample of similar geometry was measured in both contact and non-contact mode to determine the effects of measuring a dielectric material. The variation between contact and non-contact modes was similar to copper and represent approximately 0.4 μm difference between the two measurements.

These same non-contact mode measurements were done for both 6.0% relative density copper foam and 55 mg/cc SiO_2 aerogel. Figure 6 is the profile of the 6.0% relative density copper foam sample. Figure 7 is a similar profile of the 55 mg/cc stepped SiO_2 aerogel sample.

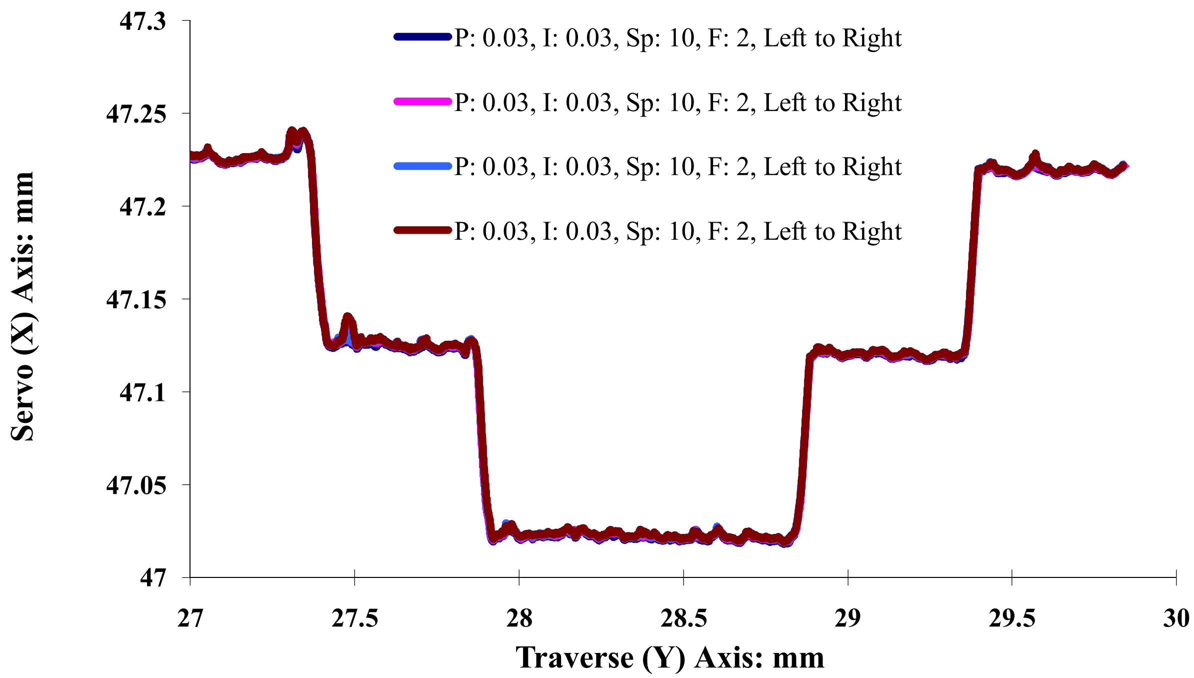

Figure 6: Scanned profile of %6.0 full density copper foam measured in a non-contact mode.

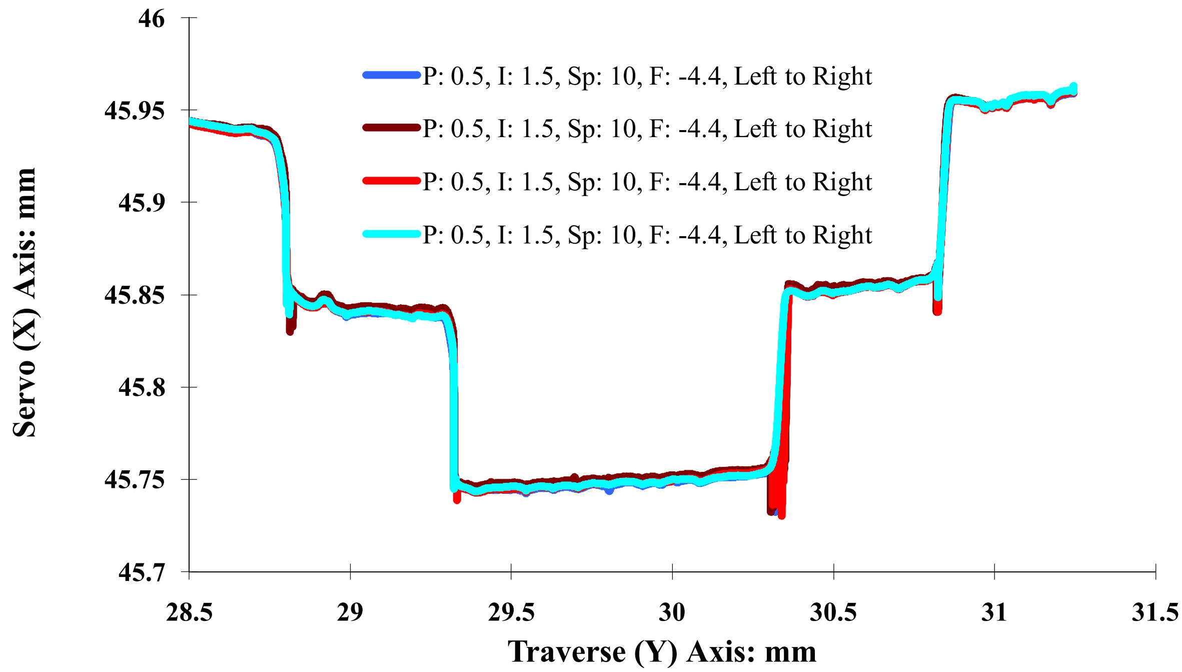

Figure 7: Scanned profile of 55 mg/cc SiO_2 aerogel.

Conclusions

The standing wave probe tested for the application of measuring low density foams has shown the ability to measure relative step heights to the micrometer level in non-contact mode without damaging the surface of the material. This probe system represents a novel way of profiling a surface of a fragile material without introducing damage to the surface complimentary to a tapping mode AFM. The combined measurement uncertainty of this system operating in non-contact mode is approximately 0.5 µm. This is the combined stacked mechanical system and the offset of the probe contact point. In addition to being applied to coordinate measuring machines in the traditional configuration, this modular probe can be integrated onto precision machine tools due to its robustness to environmental effects and minimal interaction with part surfaces.

[1] Bauza, M.B., Hocken, R.J., Smith, S.T., Woody, S.C., "Development of a virtual probe tip with an application to high aspect ratio microscale features," *Rev. Sci. Instrum.* **76**, 095112 (2005)
[2] Bauza, M.B., Woody, S.C., Smith, S.T., Hocken, R.J., "Development of a Rapid Profilometer with an Application to Roundness Gauging." *Precision Engineering*. **30** (4); 406-413, (2006)
[3] Seugling, R.M., *et al*. "Investigating Scaling Limits of a Fiber Based Resonant Probe for Metrology Applications*", Proceedings of the 23rd Annual ASPE Meeting*, Portland, OR. (2008).
[4] Bauza, M.B, *et al*, "Microscale Metrology Using Standing Wave Probes", *", Proceedings of the 23rd Annual ASPE Meeting*, Portland, OR. (2008).